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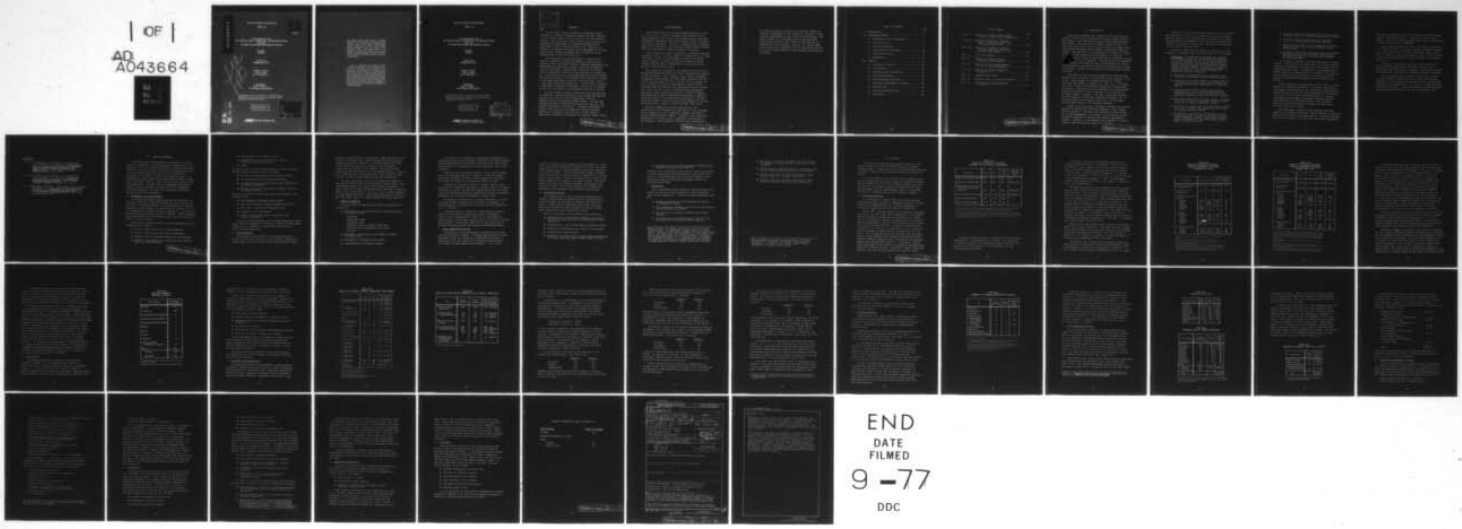

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HEALTH SYSTEMS DIVISION NOTE

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EVALUATION OF THE AIR FORCE CLINICAL LABORATORY AUTOMATION SYSTEM (AFCLAS) AT WRIGHT-PATTERSON USAF MEDICAL CENTER

VOLUME I
Summary

January 1977
(Updated May 1977)

Richard C. Brooks
Irving J. Casey
Paul W. Blackmon, Jr.

Approved by
Harry E. Emlet, Jr.
Vice President—Health Systems

Conducted for, and in cooperation with, the Directorate of Medical Plans and Resources, Office of the Surgeon General, Headquarters United States Air Force.

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ABSTRACT

The Air Force Clinical Laboratory Automation System (AFCLAS) is a medical information system that was installed in the clinical laboratories of two U.S. Air Force medical centers. This two-volume report presents the findings of an evaluation of the impacts of installing AFCLAS at the USAF Medical Center, Wright-Patterson AFB. The goal of AFCLAS is to improve the operation and management of clinical laboratories, thereby enhancing the contribution of the laboratories to quality patient care.

The evaluation plan was developed by identifying 58 potential impacts of introducing AFCLAS in place of the existing manual information system. Subjects addressed by the hypotheses included clerical tasks inside and outside the clinical laboratory; completeness of the medical records; time for processing laboratory test requests; and acceptance by, or satisfaction of, various personnel and patient groups. Data were collected at two different times—the first, period X, was before AFCLAS was installed, and the second, period Y, was after AFCLAS was operational. The evaluation included a cost-benefit analysis to determine the net cost of AFCLAS, as well as an analysis of the nondollar benefits of AFCLAS.

The cost-benefit analysis showed that the expected cost of operating a clinical laboratory using AFCLAS was $382,123 more per year than the cost of operating a clinical laboratory using the previous manual system. The one-time installation cost of AFCLAS was an additional $91,631. The nondollar benefits of AFCLAS are: probable improvement in patient care, provision of cumulative reports, improved legibility of reports, easy retrieval of test results, additional information on reports, and improved report format.

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Lt.Col. Melvin B. Dobbs, Directorate of Medical Plans and Resources, and Dr. (Lt.Col.) Rudolf G. Bickel and Lt.Col. Nedd D. Mockler, Office of the Assistant Secretary of Defense (Health Affairs), Tri-Service Medical Information System (TRIMIS) Program Office, significantly contributed to the design of the evaluation plan.

The authors are grateful to the members of the Air Force Management Engineering Teams for their invaluable contribution to the evaluation. Capt. Aubrey F. Hunt, Chief, Management Engineering Team, Andrews Air Force Base, served as the data collection team chief for the Air Force and coordinated the data collection at both the USAF Medical Center, Wright-Patterson AFB, and Malcolm Grow USAF Medical Center, Andrews AFB. Capt. Gerald R. Riley, Wright-Patterson Management Engineering Team, served as the project officer at Wright-Patterson AFB, provided consultative assistance to ANSER in the study design, and managed and participated in the data collection effort. Capt. Riley was ably assisted in the data collection by Lt. Thomas R. Porter and SSgt. Gary Clark.

The staff members of Analytic Services Inc. who contributed to the research and publication of this document are too numerous to list completely; however, the work of several deserves special thanks. Richard F. Corn, while not appearing as an author, made a noteworthy contribution to the research. Miss Francine P. Shorter also contributed to

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the results presented herein by her diligent efforts in computer programming and data reduction. Eileen P. Neely assisted considerably in the review of the document. The work of members of the ANSER Publications Department significantly improved the clarity of the text and the presentation of the tables. Finally, the authors thank Kitty Salazar for coordinating all of the typing and also for typing large portions of this document during several revisions.

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I. INTRODUCTION

This report presents the findings of the evaluation of the Air Force Clinical Laboratory Automation System (AFCLAS) being used at the USAF Medical Center, Wright-Patterson AFB, Ohio (MCWP). The evaluation at MCWP is the first part of a two-part study that is also evaluating AFCLAS at another site, the Malcolm Grow USAF Medical Center, Andrews AFB, Maryland (MGMC). The purpose of the evaluation is to assess the impact of AFCLAS on the operation and management of a clinical laboratory and on users and beneficiaries of laboratory results outside the clinical laboratory. The results of the evaluation are intended to aid those who must decide whether the AFCLAS system should be introduced at other Air Force medical centers and whether it should be continued or terminated where already installed.

The report of the evaluation performed at MCWP has been prepared in two volumes, of which this volume (Summary) is the first. (This volume is an updated version of a report initially distributed in January 1977 [Ref. 1].) In Chapter II of this volume, the evaluation methods are summarized by presenting a discussion of the hypotheses to be investigated, a brief discussion of data collection, and an overview of the major areas of analysis. The most significant findings of the evaluation at MCWP are presented in Chapter III. A previous report, the evaluation plan [Ref. 2], provides a detailed description of the evaluation methods.

Volume II of this report (Analysis) provides the detailed analysis to support the findings presented in this volume. The two volumes of the report were planned to allow Volume I to be read independently of Volume II, which may be omitted or used as reference to support the findings presented in Volume I. However, it was assumed that a reader of Volume II would be familiar with the material in Volume I.

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AFCLAS is a medical information system that the Air Force has installed in the clinical laboratories of two Air Force medical centers. The immediate goal of AFCLAS is to improve the operation and management of the clinical laboratory and, thereby, ultimately to enhance the laboratory's contribution to the quality of patient care.

The design objectives for AFCLAS are specified in the Request for Proposals (RFP) for AFCLAS [Ref. 3], as follows:

> Objectives: The proposed data system will provide the necessary capability to assist in the operation of clinical laboratories and to improve management of these facilities. The proposed system will aid laboratory supervisors by providing patient summary reports (such as complete test results), as well as current test data needed to evaluate performance of laboratory sections. The proposed system shall accomplish these objectives by:
>
> - Providing online monitoring of continuous flow laboratory instruments for more accurate results.
> - Minimizing the clerical workload in the laboratory by preparing test work lists, and obviating the need for repeat manual transcribing of laboratory results.
> - Providing an effective means for maintaining extensive quality control procedures heretofore unavailable because of the time-consuming file search and extensive manual calculations involved.
> - Providing rapid access to patient files. Retrieved files will contain all pertinent laboratory information in an orderly, meaningful format.
> - Providing for rapid entry of patient identification data, test requests, test results and the filing of completed patient records.
> - Maintaining a non-patient related data file for further reference to clinical data used in diagnostic laboratory studies. This should allow for periodic adjustment of laboratory normal ranges based on age/sex criteria.

- Providing instantaneous monitoring of complete and incomplete work at a central location at the console.
- Providing emergency laboratory test results as soon as the examinations have been completed.
- Providing data output for the laboratory Quarterly Laboratory Test Report, and the monthly In/Out Patient Report.
- Providing a more rapid turnaround time for requests generated outside the facility by significantly decreasing the amount of clerical time required for data processing.

The hardware, software, and functional operation were defined in the contract with the vendor, and these technical aspects of AFCLAS were evaluated prior to acceptance of the system by the Air Force. Therefore, it was assumed that AFCLAS operated in compliance with the terms of the contract during period Y and the preceding 3 months during which hospital personnel became accustomed to the operation of AFCLAS.

AFCLAS was procured and managed as if it were a turnkey system with standard components. In reality, AFCLAS was a developmental system because the vendor had to significantly modify software to meet Air Force requirements, and because it was the first clinical laboratory system to include a comprehensive operational microbiology software package. Since AFCLAS was a development system, some potential benefits of the system were not realized at the time we collected data on the system.

The USAF Medical Center, Wright-Patterson AFB, Ohio (MCWP) is a 320-bed, 21-bassinet, general medical and surgical hospital with a large outpatient service. Inpatient bed-days for FY 1975 totaled 93,137, and there were 8,861 admissions.

The average occupancy rate was 78.5 percent, and the average length of stay was 10.5 days. Outpatient visits totaled 419,841. The staff totaled approximately 1,100. Expenditures in that same year were $13,500,000.

MCWP is accredited by the Joint Commission on Accreditation of Hospitals and has several approved residency programs. Also, MCWP operates as a military consultant center, direct referral hospital, and an area medical center for Continental United States (CONUS) Area 3, which includes 12 base medical facilities.

Included in the present services of the hospital are general medical and surgical services, intensive care, psychiatric services, physical therapy, occupational therapy, and appropriate inpatient and outpatient ancillary services.

The evaluation effort started in June 1974. A draft evaluation plan was completed in July 1974, then revised, expanded, and pretested at USAF Medical Center, Keesler AFB, Mississippi in December 1974. The plan was further modified based on the pretest. Data were collected at MCWP from March through May 1975, and again from March through May 1976.

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(1) R. C. Brooks, R. G. Carlisle, I. J. Casey, and P. W. Blackmon, Jr. HSDN 77-1—Evaluation of the Air Force Clinical Laboratory Automation System (AFCLAS) at Wright-Patterson USAF Medical Center. Falls Church, Virginia: Analytic Services Inc., 1977.

(2) R. C. Brooks, R. G. Carlisle, I. J. Casey, and P. W. Blackmon, Jr. HSDN 77-3—Evaluation Plan for the Air Force Clinical Laboratory Automation System (AFCLAS). Falls Church, Virginia: Analytic Services Inc., 197 .

(3) United States Air Force. "Performance Specifications." Attachment II of Air Force Clinical Laboratory Automation System—Request for Proposals. L. G. Hanscom Field, Massachusetts: Air Force Systems Command, 1973.

II. EVALUATION METHODS

The ANSER study team designed the evaluation in cooperation with personnel in the Directorate of Medical Plans and Resources, Office of the Surgeon General, Headquarters United States Air Force; personnel at the Data Systems Design Center at Gunter AFS, Alabama; and the Chairman, Department of Pathology, and his staff at each of the two test sites. We pretested the study design at the USAF Medical Center, Keesler AFB, Mississippi, and as a result of the pretest improved the evaluation plan. Personnel from the Management Engineering Teams (METs) at each test site were primarily responsible for data collection, but they also cooperated in designing the data collection techniques.

A. Hypotheses To Be Investigated

To develop the AFCLAS evaluation plan, we identified the potential impacts of introducing AFCLAS in place of the existing manual information system. We considered the anticipated importance of each impact, the possibility of measuring it, and the feasibility of collecting data to measure it. As a result, we hypothesized 58 specific effects of AFCLAS. These hypotheses guided development of the evaluation plan, the data collection effort, and the analysis.

The potential changes covered by the 58 hypotheses may be categorized as follows:

- Clerical tasks inside the clinical laboratory
- Clerical tasks outside the clinical laboratory
- Average time for processing laboratory test requests
- Errors in test request slips arriving at the clinical laboratory reception desk

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- Completeness of the medical record
- Acceptance by, or satisfaction of, various personnel and patient groups
- Other.

For one or more of the following reasons, we did not include several expected changes in the evaluation:

- The estimated magnitude of the change was small.
- The change could not be defined precisely.
- The data collection would unduly disrupt laboratory or hospital operation.
- The data collection would be too expensive for the information gained.

Examples of potential changes that were not included in the evaluation are:

- Time laboratory personnel spent walking
- Time spent maintaining backup system proficiency
- Skill level required for laboratory staff
- Accuracy of test performance
- Number of physician walk-in inquiries to the clinical laboratory.

We tested each hypothesis using standard statistical techniques wherever possible and necessary. Where such statistical testing was not conducted, we used other techniques to investigate the hypothesis.

B. Data Collection

MET personnel and members of the study team were to collect data at each test site at two different times—one, called period X, before AFCLAS was installed and one, called

period Y, after AFCLAS was operational. Data collected during period X is baseline data, and data collected during period Y represents AFCLAS in operation. All data collection at the Wright-Patterson facility is complete, and this report summarizes the results of that effort. The period X data collection has been completed at the Andrews facility. Period Y data collection will be completed and a final report written as soon as planned AFCLAS modifications are operational.

We used cost-benefit analysis to evaluate the benefits and costs of AFCLAS that can be assigned a dollar value. Some anticipated benefits and costs either cannot be assigned a dollar value or the data collection effort required to determine their value is prohibitive. *Nondollar benefits* were assessed in other appropriate ways. They become particularly significant when the dollar costs of a system exceed the dollar benefits.

C. Nondollar Benefits

The basic types of benefits and costs not quantified in dollars are:

- Acceptance by, or satisfaction of, various personnel and patient groups
  - Physicians
  - Registered nurses
  - Laboratory staff
  - Outpatient Medical Records (OMR) staff
  - Admissions and Dispositions (A&D) staff
  - Patients
- Physicians' perceptions of the impact of AFCLAS on patient care
- Timeliness of laboratory test results
- Completeness of the medical record.

The analysis of acceptance or satisfaction measured prior receptiveness and actual response to AFCLAS using scores derived from questionnaires and data from interviews. We interviewed a random sample of 25 physicians, all A&D personnel, and all OMR personnel.

Acceptance and satisfaction affect factors such as absenteeism and personnel turnover. However, we did not measure the effect of AFCLAS on these factors because the evaluation period was too short for a significant change to occur.

Although the laboratory exists to support patient care, the impact of laboratory operations on patient care is extremely difficult to assess. We used the questionnaires and the interviews with the random sample of physicians to assess physicians' perceptions of the impact of AFCLAS on patient care.

An important objective of a clinical laboratory is to provide test results to physicians as quickly as possible. We investigated the turnaround time for both routine requests and for *stat* requests.

A complete medical record for a patient should contain reports of all completed laboratory tests. We measured medical record completeness in terms of the percentage of a random sample of laboratory reports filed in the medical records approximately 1 month after completion of the tests, and we studied inpatient records and outpatient records separately.

D. Dollar Benefits and Costs

The objective of the cost-benefit analysis was to determine the net cost of AFCLAS. To compute the net cost of tasks performed inside the laboratory, we determined the cost of laboratory staff time saved or of additional time required as a result of task changes due to AFCLAS. A *task change*

could be a change in the frequency or the duration of a task, or it could be the addition or deletion of a task. We determined the net cost of tasks performed outside the laboratory by a similar method. The only significant change in supply costs that could be directly related to AFCLAS was in the net cost of paper forms. Finally, the direct dollar cost of the AFCLAS system was included in the total net cost. Recurring direct costs are for hardware, software, maintenance, and electrical power. The one-time direct cost includes construction of the computer room and system installation.

E. Intervening Factors

An important part of this study was identification of changes in laboratory or hospital policy or operation that occurred between the beginning of period X and the end of period Y, that were not associated with AFCLAS, and that could have affected the data collected to evaluate AFCLAS. These changes are called intervening factors.

Several intervening factors affected our evaluation:

- Introduction of new automated equipment (the HYCEL-17 and the Technicon Stat Ion) at the beginning of the evaluation
- Introduction of the Civilian Health Screening Program
- Operation of the Primary Care Clinic in the evening
- Introduction of ward clerks
- Adoption of a policy that no longer requires physicians to initial laboratory reports before they are filed

- Introduction of the automated Medical Administrative Management System-Revised (MAMS-R)*.

Although these intervening factors had an impact on the data, a limited sensitivity analysis indicated that errors due to them did not significantly alter the final results of the evaluation except for physician acceptance of both the laboratory and AFCLAS.

F. Assumptions

The 58 hypotheses—which served to guide the study, the methods of analysis, and the methods of data collection—imply several assumptions. Some of the most fundamental ones are:

- Changes identified by the hypotheses are effects of implementing AFCLAS.
- The hypothesized changes account for the most significant changes due to AFCLAS.
- The case mix of inpatients seeking help remains constant.
- The proportion of each beneficiary class for both inpatients and outpatients remains constant.

---

*MAMS-R changed the routine activities of both clinic and A&D personnel. In outpatient clinics, the clinic staff members complete a mark-sense encounter form for each patient visit. For inpatients, the A&D staff use a CRT terminal to enter information relevant to each admission, discharge, and interward transfer. It is possible that in responding to questions about computers, staff members may not have distinguished the effects of AFCLAS from those of MAMS-R.

- The values of several variables* that are affected by workload vary directly with the volume of tests requested.
- During period Y, AFCLAS operates in compliance with the RFP specifications and terms of the contract.
- The unit times for the tasks time studied remain constant over small changes in workload.
- The unit times for the tasks time studied remain constant over small changes in staffing levels.

---

*This assumption was made when adjusting the following variables for the change in workload between period X and period Y: number of old request slips, lines on worksheets, and inquiry phone calls.

III. RESULTS

This section summarizes the principal results of the AFCLAS evaluation at the USAF Medical Center at Wright-Patterson AFB. It also outlines system improvements suggested by hospital staff and lists several alternative courses of action.

In this evaluation, we estimate the net change in non-dollar benefits and costs as a result of introducing AFCLAS. The net change in costs is the difference between the costs of operating the clinical laboratory during period Y with AFCLAS support and the (hypothetical) costs of processing the period Y workload using period X (manual) methods.

A. Statistical Studies

To investigate in detail items that are particularly significant either to users of laboratory results or for the operation and management of the clinical laboratory, we studied activities outside and inside the laboratory.

Table III-1 lists the results of the studies of external activities. For the first item, completeness of outpatient medical records, we determined the percentage of a random sample of outpatient laboratory reports filed in the medical records approximately 1 month after completion of the tests. The results indicate that the percentage of reports filed increased by 6.4 (from 83.7 in period X to 90.1 in period Y), and the increase is statistically significant at the 0.05 level. The increase may be due to the fact that the information is more complete and readable on the printed AFCLAS reports; however, hospital policy on physician initialing of reports was changed after period X. In period X, reports were distributed to the clinics, initialed by the physicians, then sent to OMR for filing. In period Y, reports were sent directly from the clinical laboratory to OMR for filing.

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TABLE III-1
RESULTS OF STUDIES OF ACTIVITIES
EXTERNAL TO THE CLINICAL LABORATORY

Activity Studied	Period X	Period Y	Change from X to Y	Statistical Significance Level
Lab Reports Filed in Outpatient Records	83.7%	90.1%	+6.4%	.05*
Lab Reports Filed in Inpatient Records	95.8%	95.0%	−0.8%	Not Significant*
Outpatient Request Slips Arriving at the Reception Desk with One or More Serious Errors	12.6%	10.4%	−2.2%	Not Significant*
Average Duration of Inquiry Phone Calls	2.05 min	2.10 min	+0.05 min	Not Significant†
Frequency of Inquiry Phone Calls	5.5/hr	4.6/hr	−0.9/hr	‡
Frequency if Adjusted for Workload	6.7/hr	4.6/hr	−2.1/hr	‡

*The level shown (if significant) is that at which the difference between the period X and period Y values is significant.

†The level shown (if significant) is that at which the ratio of period X time to period Y time is significant.

‡Statistical significance was computed for the nine 1-hour time intervals between 0730 and 1630 hours. The difference was statistically significant at the .01 level for four time intervals, but statistical significance for the overall change could not be computed because the assumptions for the statistical test employed do not hold for other than small time increments throughout the day (i.e., Poisson distribution with F test).

We used a similar method to investigate the second item, completeness of inpatient medical records. The percentage of inpatient reports filed decreased slightly (from 95.8 in period X to 95.0 in period Y), but the decrease is not statistically significant.

Outpatient request slips occasionally arrive at the reception desk with errors. We defined a serious error in an outpatient test request slip arriving at the reception desk as an error in patient name, Social Security number, or clinic name. Serious errors decreased by 2.2 percent (from 12.6 in period X to 10.4 in period Y), but the decrease is not statistically significant. Thus, the mark-sense request slips used with AFCLAS did not appear to change the error rate significantly.

We sampled the duration and frequency of inquiry phone calls to the clinical laboratory during randomly selected time intervals. The duration of an inquiry call increased slightly, but not significantly (from 2.05 minutes in period X to 2.10 minutes in period Y). The frequency decreased from 5.5 per hour in period X to 4.6 per hour in period Y. We assumed that the frequency of telephone inquiries was linearly related to the number of tests requested (workload). If the period X frequency is adjusted for the number of tests requested in period Y, it becomes 6.7 per hour over all sampling intervals. These results indicate that the frequency of telephone inquiries decreased by 2.1 per hour. For statistical significance, see Table III-1.

Tables III-2A and III-2B present results for activities inside the clinical laboratory. The first item, the average time a patient spent in the clinical laboratory for specimen collection, increased 12.8 minutes (from 18.9 minutes in period X to 31.7 minutes in period Y), and the increase is statistically significant at the 0.002 level.

The average time a patient spent standing in line and being served at the reception desk increased slightly (from 0.42 minutes in period X to 0.48 minutes in period Y), and the increase is statistically significant at the 0.05 level.

TABLE III-2A
RESULTS OF STUDIES OF INTERNAL CLINICAL LABORATORY ACTIVITIES
(Unadjusted Mean Times)

Activity Studied	Period X	Period Y	Change From X to Y	Statistical Significance Level*
Patient Time in Clinical Laboratory for Specimen Collection	18.9 min	31.7 min	+12.8 min	.002
Patient Service Time at the Reception Desk	0.42 min	0.48 min	+0.06 min	.05
Laboratory Report Turnaround Time				
Inpatients				
Hematology	3.30 hr	22.69 hr	+19.39 hr	.001
Urinalysis	3.03 hr	22.54 hr	+19.51 hr	.001
Chemistry†	--	67.06 hr	--	--
Microbiology	61.82 hr	97.63 hr	+35.81 hr	.001
Parasitology‡	10.90 hr	--	--	--
Serology	22.96 hr	15.88 hr	−7.08 hr	.05
Outpatients				
Hematology	2.61 hr	11.89 hr	+9.28 hr	.001
Urinalysis	9.30 hr	18.30 hr	+9.00 hr	.001
Chemistry†	--	159.09 hr	--	--
Microbiology	36.51 hr	62.85 hr	+26.34 hr	.001
Parasitology‡	44.49 hr	--	--	--
Serology	48.20 hr	51.15 hr	+2.95 hr	Not Significant
Stat Report Turnaround Time§				
Chemistry	9.79 hr	14.59‖ hr	+4.80 hr	.001
Hematology	1.74 hr	5.51 hr	+3.77 hr	.001
Urinalysis	0.84‖ hr	6.14‖ hr	+5.30 hr	.001

*Probability that a change of the given magnitude could occur by chance alone is less than the stated significance level.

†Period X data in Chemistry was unreliable due to concurrent installation of the HYCEL-17.

‡The small number of requests in Parasitology during period Y was processed by Microbiology. The effect on the data for Microbiology should be minimal.

§The turnaround times for *stat* reports presented in this table are the elapsed times for the paper reports. The physicians usually receive *stat* test results by telephone in a significantly shorter period of time.

‖Times for one or two test reports (per item) with unusually long turnaround times (> 7 days) were arbitrarily set at 24 hours in order to make the mean turnaround time more realistic.

TABLE III-2B
RESULTS OF STUDIES OF INTERNAL CLINICAL LABORATORY ACTIVITIES
(Adjusted* Mean Times)

Activity Studied	Period X	Period Y	Change From X to Y	Statistical Significance Level†
Patient Time in Clinical Laboratory for Specimen Collection	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Patient Service Time at the Reception Desk	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Laboratory Report Turnaround Time				
Inpatients				
Hematology	3.30 hr	22.69 hr	+19.39 hr	.001
Urinalysis	3.03 hr	22.54 hr	+19.51 hr	.001
Chemistry‡	--	46.03 hr	--	--
Microbiology	56.42 hr	81.78 hr	+25.36 hr	.001
Parasitology§	10.90 hr	--	--	--
Serology	22.96 hr	15.88 hr	−7.08 hr	.05
Outpatients				
Hematology	2.61 hr	11.89 hr	+9.28 hr	.001
Urinalysis	9.19 hr	18.30 hr	+9.11 hr	.001
Chemistry‡	--	35.77 hr	--	--
Microbiology	35.05 hr	53.09 hr	+18.04 hr	.001
Parasitology	44.49 hr	--	--	--
Serology	48.20 hr	51.15 hr	+2.95 hr	Not Significant
Stat Report Turnaround Time‖				
Chemistry	6.29 hr	7.99 hr	+1.70 hr	.05
Hematology	1.73 hr	5.25 hr	+3.52 hr	.001
Urinalysis	0.84 hr	5.29 hr	+4.45 hr	.001

*For routine reports, any turnaround times greater than 10 days (14 days in Microbiology) were set at 10 days (14 days). Routine requests with turnaround times in excess of 10 days (14 days) were probably either lost or excessively delayed in verification. For *stat* reports, any turnaround times greater than 24 hours were set to 24 hours. Requests with turnaround times in excess of 24 hours probably either were not true *stat* requests or were not processed promptly due to the results of the test already having been reported by telephone.

†Probability that a change of the given magnitude could occur by chance alone is less than the stated significance level.

‡Period X data in Chemistry was unreliable due to concurrent installation of the HYCEL-17.

§The small number of requests in Parasitology during period Y was processed by Microbiology. The effect on the data for Microbiology should be minimal.

‖The turnaround times for *stat* reports presented in this table are the elapsed times for the paper reports. The physicians usually receive *stat* test results by telephone in a significantly shorter period of time.

We defined turnaround time in period X as the interval between the arrival of the test request in the laboratory and the report being ready for distribution. For all *stat* requests and for routine requests that arrive between 0600 and 2000 hours, time of arrival of a request is actual clock time. We assigned an effective time of 0600 hours to routine requests that arrive between 2000 and 0600 hours because the specimens are not taken until morning draw rounds. We defined turnaround time in period Y as the interval between reading the request into AFCLAS and printing the reports. Since routine reports are printed in the early morning, we assigned them an effective completion time of 0400 hours. *Stat* reports are printed immediately upon verification of the results, and the report shows the correct time of printing, which is approximately the same as time of verification. We would have liked to use time of verification for routine requests also, but this time is not available from AFCLAS.

Different turnaround times are characteristic of different laboratory sections due to the nature of the tasks performed. Turnaround time was investigated separately for *stat* and routine requests, and by laboratory section, as appropriate. Routine requests were further subdivided into those associated with inpatients and those associated with outpatients.

As shown in Tables III-2A and III-2B, the mean turnaround time for routine laboratory requests increased in all sections for both inpatients and outpatients with the exception of Serology requests for inpatients. We arbitrarily assigned a time of 10 days (14 days for Microbiology) to each request that actually exceeded 10 days (14 days) because we assumed that these reports were either lost or excessively delayed in verification. For statistical significance of changes in turnaround time for routine requests, see Tables III-2A and III-2B.

A probable explanation for the increase in turnaround times for routine requests is the fact that reports in period X were distributed at 1200 hours and 1700 hours on the same day that processing was completed; in period Y, reports of laboratory test results were printed for distribution in the early morning of the day following the completion of processing.

We computed turnaround time for *stat* requests separately for the Chemistry, Hematology, and Urinalysis sections. The turnaround times for *stat* requests presented in Tables III-2A and III-2B are the elapsed times for the paperwork. The physicians usually receive *stat* test results by telephone in a significantly shorter time period. As shown in Tables III-2A and III-2B, mean turnaround time increased from period X to period Y for each section. We arbitrarily assigned a time of 24 hours to each *stat* report that actually exceeded 24 hours because we assumed that physicians who did not have the results of a *stat* test after 24 hours would call the laboratory for those results. Again, the mean adjusted turnaround time for *stat* reports increased from period X to period Y for each of the three sections. For statistical significance of turnaround time for *stat* reports, see Tables III-2A and III-2B. The increase in turnaround times for the paper reports probably reflects an increase in turnaround times for reporting *stat* results but the magnitude of the change is not known.

B. Time Studies

We analyzed personnel time spent on tasks directly affected by AFCLAS. For the tasks studied, Table III-3 summarizes the net change in hours per quarter, by personnel category. In the column for the net hours, a positive number indicates a net increase and a negative number indicates a net savings in time due to the installation of AFCLAS. Net

TABLE III-3
TIME STUDY SUMMARY
(Workhours per Quarter)

Personnel Category*	Net Change (hours per quarter)†
Clinic Staff	874
Lab Technician	506
Outpatient Medical Records (OMR) Staff	221
Inpatient Medical Records (IMR) Staff	71
Admissions and Dispositions (A&D) Staff	55
Ward Nurse	15
Corpsman	15
Lab Officer	−3
Lab Supervisor	−10
Noncommissioned Officer in Charge (NCOIC) of Laboratory	−16
Patient	2,021
Staff Total	1,728
Patient Total	2,021

*A negative 6 hours per quarter for the receptionist is taken into account in the times shown in Table III-9.

†Values given are based on workload for January, February, and March 1976.

times increased for eight of the 11 personnel categories observed, and the decreases that did occur were very small.

Table III-4 presents the results of time studies of individual tasks inside the clinical laboratory; Table III-5 presents similar results for individual tasks external to the laboratory. We also studied the following tasks, but they are not included in either Table III-4 or III-5 because AFCLAS did not produce a change in them:

- File quality control reports
- Perform statistical analysis for quality control
- Perform statistical analysis of patient results by population
- Calculate test results
- Check errors in test results (by laboratory officers)
- Call ward or clinic to report *stat* results.

Even though AFCLAS prints *stat* results in most critical-care wards and in some clinics, the last task showed no change because the laboratory policy of telephoning the requesting physician to report the results of each *stat* test was continued in period Y.

We included the time required to enter test requests into AFCLAS as part of the expanded receptionist duties and not in the time studies.

C. Acceptance and Satisfaction

We used scores derived from responses to questionnaires to measure patient satisfaction with the clinical laboratory, job satisfaction of laboratory staff, physician satisfaction with the clinical laboratory, and physician and registered nurse acceptance of AFCLAS. In period X and period Y, each

TABLE III-4
RESULTS OF INTERNAL CLINICAL LABORATORY TIME STUDIES

Task	Period X (hours worked)	Period Y (hours worked)	Net Cost of AFCLAS* (work hours per quarter by personnel category)
Prepare Administrative Reports†	9.0	6.0	−3.0 Lab Officer
	22.0	3.5	−18.5 NCOIC of Lab
	15.5	5.2	−10.3 Lab Supervisor
File Request Slips or	36.3	15.6	−20.7 Lab Supervisor
Computer Request Cards	36.3	15.5	−20.8 Lab Technician
File Worksheets and Log Books	5.5	4.1	−1.4 Lab Supervisor
Miscellaneous New Filing Tasks	--	2.2	2.2 NCOIC of Lab
Clear Files	4.0	0.0	−4.0 Lab Technician
Complete Test Request Slips	9.0	0.0	−9.0 Lab Technician
or Computer Request Cards	6.0	0.0	−6.0 Receptionist
Enter Test Results on Slips or into Computer‡	154.8	630.4	475.6 Lab Technician
Complete Worksheets	175.0	0.0	−175.0 Lab Technician
Label Blood Specimens	233.4	500.8	267.4 Lab Technician
Prepare for Morning Draw Rounds	22.5	33.8	11.3 Lab Technician
Review and Certify Test Results§	169.1	79.7	−89.4 Lab Technician
Operate CREATE Computer System‖	176.7	--	−176.7 Lab Technician
Retrieve Old Reports to Answer Inquiries	26.7	0.0	−26.7 Lab Technician
Reconcile Unfinished Work Report	--	201.5	201.5 Lab Technician
Enter Cytology Results in AFCLAS	--	112.0	112.0 Lab Supervisor
Telephone to Inquire	127.8	89.9	−37.9 Lab Technician
about Test Results	127.7	89.8	−37.9 Ward Nurse
Patient Time in the Clinical Lab	4,410.0	7,396.7	2,986.7 Patient

*Net cost is for January, February, and March 1976.

†Only those internal laboratory reports affected by AFCLAS.

‡Includes validation of tests entered via CRT terminal.

§Does not include validation of tests entered via CRT terminal.

‖CREATE, a time-sharing computer system at Wright-Patterson AFB, was used by the Chemistry Section to generate worksheets during period X.

TABLE III-5
RESULTS OF TIME STUDIES EXTERNAL TO THE CLINICAL LABORATORY

Task	Period X (hours worked)	Period Y (hours worked)	Net Cost of AFCLAS* (work hours per quarter by personnel category)	
File Reports in Outpatient Medical Records	753.6	975.0	221.4	OMR Staff
File Reports on Wards or in Inpatient Medical Records	79.5	47.0	−32.5	Ward Nurse
	79.5	94.1	14.6	Corpsman
	67.5	138.5	71.0	IMR Staff
Prepare and File Cumulative Summaries	128.4	128.4	0.0	Physician
Complete Test Request Slips or Computer Request Cards	965.5	0.0	−965.5	Patient
	130.9	216.5	85.6	Ward Nurse
	107.3	981.3	874.0	Clinic
	0.0	34.1	34.1	A&D Staff
Obtain MAMS-R Printout of A&D Transactions for AFCLAS Use	--	21.3	21.3	A&D Staff

*Net cost is for January, February, and March 1976.

personnel group completed one or more questionnaires specific for that group. We obtained response rates between 89 percent and 100 percent.

In each period, a random sample of 200 patients received the patient questionnaire. We computed the mean score for each patient to determine if the patient was satisfied or dissatisfied. Although patients were generally satisfied with the clinical laboratory in both periods, the number satisfied decreased as shown by the specific results, which are statistically significant at the 0.01 level.

Satisfied in period X - 87.9%
Satisfied in period Y - 82.5%

Of the 15 patient questions, the responses to the question on waiting time evidenced the greatest decrease in satisfaction. As reported in the section on statistical studies, mean patient waiting time increased from period X to period Y by 12.8 minutes. The reasons for the changes in other responses are not apparent. Innovation in the clinical laboratory might be an explanation, or waiting time might influence responses to other questions.

In both periods, laboratory staff completed a job satisfaction questionnaire. The results are:

	Period X	Period Y
Satisfied	63%	66%
Neutral	13%	13%
Dissatisfied	24%	21%

Although job satisfaction was slightly higher in period Y than in period X, the change is not statistically significant at the 0.05 level.

Physicians completed two questionnaires in both periods. The first questionnaire measured physician satisfaction with the clinical laboratory, as follows:

	Period X	Period Y
Satisfied	20%	19%
Neutral	45%	35%
Dissatisfied	35%	46%

The percentage of physicians who were dissatisfied with the clinical laboratory increased from period X to period Y. Information from the interviews with a random sample of physicians indicates that the increase was probably due to intervening factors, such as the introduction of the HYCEL-17.

The period X version of the second questionnaire measured acceptance of the change from a manual to an automated system. The period Y version measured acceptance of AFCLAS after it became operational. The results are as follows:

	Period X	Period Y
Favorable	77%	33%
No change	22%	31%
Unfavorable	1%	36%

In period X, most physicians had limited information on AFCLAS. An average of 30 percent of the responses to individual questions either were "no opinion" or were blank. In period Y, the average was 8 percent.

AFCLAS did not meet the physicians' expectations (as of April 1976), since acceptance decreased on all 29 questions. The decrease is statistically significant at the 0.001 level for each question.

The period X questionnaire for registered nurses also measured acceptance of change from a manual to an automated system. The period Y questionnaire measured acceptance of AFCLAS after it became operational. The results are as follows:

	Period X	Period Y
Favorable	74%	31%
No change	23%	36%
Unfavorable	3%	33%

Like physicians, the nurses had limited information on AFCLAS in period X. An average of 31 percent of the responses to individual questions either were "no opinion" or were blank. In period Y, the average was 18 percent. AFCLAS did not meet the nurses' expectations (as of April 1976), since acceptance decreased in period Y on all 16 questions. The decrease is statistically significant at the 0.001 level for each question.

The phenomenon of resistance to innovation or change, called *cultural lag*, is well documented in the sociological literature. This experience suggested that the physicians' and nurses' acceptance and enthusiasm for AFCLAS would be limited because of the short time interval between technical acceptance of AFCLAS by the Air Force (October 1975) and the administration of the questionnaires (April 1976).*

During the last week of March 1976, we interviewed all members of the Outpatient Medical Records (OMR) staff (total 11) and all members of the Admissions and Dispositions (A&D) staff (total eight) to determine their perception of the

* AFCLAS was not functionally operational until the end of January 1976.

impact of AFCLAS on their work. The OMR staff perceived that the time spent filing was longer and that the volume of reports increased. They were evenly divided on whether filing was easier or more difficult.

The A&D staff perceived an increase in workload that may have been due to AFCLAS, MAMS-R, or both. In general, they accepted AFCLAS.

D. Nondollar Benefits

Physicians are the primary users of laboratory reports and therefore, their responses to the questionnaires and during the interviews form the basis for assessing nondollar benefits. In addition we studied some of these benefits quantitatively.

Physicians in general felt that the nondollar categories improved with the installation of AFCLAS. As given in Table III-6 physicians perceived an improvement in 13 instances and a deterioration in seven instances.

On the questionnaires, physicians responded that patient care deteriorated, but in the interview they felt that it improved. The difference in perception may have resulted because the interviews were conducted about 2 months later (June 1976) than administration of the questionnaires (April 1976). The ambiguity may also indicate that physicians do not feel that AFCLAS significantly affected patient care.

In both the questionnaires and interviews physicians reported that they felt AFCLAS improved or that there was a benefit with respect to cumulative reports, retrieval of test results, report format, and the amount of patient information provided. On the questionnaires physicians reported that lost reports and turnaround time for routine reports deteriorated but in the interviews they reported that these two items improved.

TABLE III-6
SUMMARY OF NONDOLLAR BENEFITS OF AFCLAS

Item	Physician Questionnaires	Physician Interview	Quantitative Data Available
Patient Care	D*	I	--
Cumulative Reports	I	I	--
Lost Reports†	D	I	Yes
Legibility of Reports	I	I	--
Turnaround Time for Routine Reports‡	D	I	Yes
Turnaround Time for *Stat* Reports§	D	D	Yes
Retrieval of Test Results	I	I	--
Report Format	I	I	--
Accuracy of Test Results‖	D	D	--
Provides More Patient Information	I	I	--

*D = deteriorated, I = improved.

†The percentage of reports filed in OMR increased significantly (.05 level). The percentage of reports filed in IMR decreased slightly but was not statistically significant.

‡Routine report turnaround time increased significantly in all departments except Serology.

§Of six determinations, turnaround time increased for all. The ratio was statistically significant at the .001 level for five and at the .05 level for one.

‖Accuracy is not directly affected by AFCLAS.

Turnaround time for *stat* reports was perceived by the physicians as deteriorating in both the questionnaires and interviews. Physicians reported that the accuracy of test results deteriorated between period X and period Y. Since AFCLAS was not designed to directly affect the way technicians perform the tests, it probably did not directly affect test accuracy. However, it may have decreased transcription errors, thereby actually improving the accuracy of reported results. The perceived decrease in test accuracy was probably due to intervening factors (e.g., the installation of the HYCEL-17 or other changes in laboratory operations) and not due to the installation of AFCLAS.

E. Dollar Benefits and Costs

For each personnel category, we first determined the number of personnel at each rank or GS grade in the category. Next we calculated the average cost for the personnel category by computing a weighted average of the direct cost to the Air Force for all personnel in the category. We based military personnel rates on the Air Force Annual Composite Standard Rate and Civil Service personnel rates on 108.44 percent of Step 4 of the GS pay scale,* both as of 1 October 1975. We then calculated the hourly and quarterly rates for each category from the annual rate (Table III-7).

Table III-8 lists direct dollar savings or costs associated with the tasks that we examined in the time studies (see Table III-3). We computed the annual costs on the basis of the rates in Table III-7. The dollar cost of the staff tasks

*AFM 26-1, Manpower Policies and Procedures, specifies this factor for costing Civil Service personnel.

TABLE III-7
PERSONNEL COST RATES

Personnel Category	Hourly Rate	Quarterly Rate	Annual Rate
Lab Officer	$13.24	$5,719	$22,876
Ward Nurse	9.40	4,062	16,247
NCOIC of Lab	9.43	4,073	16,291
Lab Supervisor	9.12	3,939	15,756
Lab Technician	6.17	2,667	10,667
IMR Staff	5.51	2,379	9,515
Clinic Staff, A&D Staff	5.23	2,258	9,031
OMR Staff, Corpsman	4.21	1,819	7,275
Patient	0	0	0

TABLE III-8
PERSONNEL COST OF TASKS TIME-STUDIED

Personnel Category	Net Change (hours per quarter)*	Quarterly Cost	Projected Annual Cost
Clinic Staff	874	$4,571	$18,284
Lab Technician	506	3,122	12,488
OMR Staff	221	930	3,722
IMR Staff	71	391	1,565
A&D Staff	55	288	1,151
Ward Nurse	15	141	564
Corpsman	15	63	253
Lab Officer	−3	−40	−159
Lab Supervisor	−10	−91	−365
NCOIC of Lab	−16	−151	−604
Patient	2,021	0	0
Staff Total	1,728	$9,224	$36,899
Patient Total	2,021	--	--
Total			$41,179†

*Values given are based on workload for January, February, and March 1976 (see Table III-3).

†AFM 25-5, *Management Engineering Policies and Procedures*, specifies an allowance factor of 11.6 percent for unproductive time.

increased by $36,899. When we include an allowance factor of 11.6 percent for unproductive time (the factor normally used in MET studies), the total increase in staff cost for the tasks is $41,179 per year.

In addition to the increase in cost associated with the tasks time studied, there were new tasks associated with AFCLAS (Table III-9). We did not do time studies of these tasks because they require that personnel be committed to them full time, whether or not the personnel are fully utilized. For example, a minimum of five persons are required to staff the computer room 24 hours a day, 7 days a week. However, it is probable that the computer room staff could assume additional duties if the policies of the Air Force Logistics Command and the hospital were changed. We computed the annual costs of the additional personnel by the same methods used to derive the costs in Table III-8.

TABLE III-9
ADDITIONAL PERSONNEL COSTS DUE TO AFCLAS

Personnel Added	Number of Persons	Projected Annual Cost*
Computer Room Staff	5.0	$49,979
Reception Personnel	2.5	22,223
AFCLAS Systems Manager	1.0	20,751
Data Base Maintenance and Routine Administration	0.5	5,275
Total		$98,228

*The annual costs for additional personnel were computed by the same methods as the costs in Table III-8.

At Wright-Patterson, the total expected dollar cost (including all of the dollar savings) of operating AFCLAS (as configured in April 1976) is $382,123 per year more than that required to operate the previous manual system. In addition, there was a one-time cost of $91,631. The recurring cost breaks down as follows:

Hardware Yearly Lease	$183,648
Maintenance Outside Principal Period of Maintenance	1,000
Software Yearly Lease	22,212
Net Yearly Cost for Paper Forms and Computer Supplies	32,500
Electric Power	3,356
Net Personnel Costs for Tasks Time Studied	41,179
Net Personnel Costs for Receptionists and Computer-Related Tasks	98,228
Total	$382,123

Note that the software cost of $22,212 per year was not expended during period Y due to a contractual technicality, but it will be a cost in the future.

F. Suggested Improvements in AFCLAS

During the interviews with hospital staff, we solicited information on ways to improve AFCLAS. The following list shows the improvements suggested by the random sample of 25 physicians and the number who listed each one when answering the question "What improvements in AFCLAS would help you?"

More terminals on wards and in clinics - 7
Better format and color of request forms - 3

Simpler retrieval of information from AFCLAS data files - 2

Video terminals in wards and clinics - 2

Better distribution system for printed reports - 2

Faster response when retrieving information - 2

Weekly cumulative reports for each inpatient - 2

Capability to change system at local level - 2

More information printed on one sheet - 2

System available more time for result inquiry (called "less downtime" by physicians) - 1

Better patient identification - 1

Capability to provide more specific directions to the laboratory technician - 1

Need for a backup system - 1

Faster terminals - 1

Cumulative reports for inpatients and outpatients - 1

On the assumption that physicians would like to see an improvement in items that had deteriorated, we list their responses, and the number who responded, to the question "What has deteriorated since AFCLAS was installed?"*

Cumbersomeness of records - 8

Format and color of laboratory requests - 8

Reports not filed - 6

Turnaround time - 5

Ease of retrieving test results - 5

Number of lost reports - 5

Availability of system for result inquiry (called "less downtime" by physicians) - 5

Turnaround time for *stats* - 5

Lost specimens - 4

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*In the interview, the question on deterioration preceded the question on improvements.

Errors in input to computer - 3
Laboratory reports sent to wrong place - 2

The Outpatient Medical Records Staff (total 11) suggested several improvements. Five respondents suggested ordering reports by terminal digit Social Security number. This suggestion will be implemented early in 1977. Four respondents suggested that there should be an easy way to determine whether the report is for an inpatient or an outpatient. One respondent wanted to be able to readily identify reports for patients whose records are not stored at Wright-Patterson. Two respondents suggested *bursting* computer reports, which is the mechanical removal of edges and the separation of computer printout sheets. Equipment to perform this operation costs less than $3,000 and could save approximately 200 hours ($4,000) per year. Two respondents suggested that AFCLAS be interfaced with MAMS-R. The Admissions and Dispositions Staff made the same suggestion.

G. Alternatives

There are several alternatives for the continued development of AFCLAS. An improved AFCLAS could be introduced into other Air Force hospitals. Such a system would provide for automated registration of patients using the laboratory and would have to be modified to correct problems identified by personnel at the test sites. The net cost of each new installation would exceed (by an amount not yet estimated) the present net cost of $382,123 per year and would have the following nondollar benefits for the Air Force:

- Probable improvement in patient care
- Provision of cumulative reports
- Improved legibility of reports

- Easy retrieval of test results
- Additional information on reports
- Improved report format
- Potential for improved turnaround time.

Alternatively, AFCLAS could be retained at the two test sites and developed further before being installed in other Air Force hospitals at a later date. The net cost of retaining AFCLAS would be approximately $382,123 per year for each site. If the current AFCLAS system is improved and expanded, the net cost will probably increase. In addition to the non-dollar benefits listed for the first alternative, the second could result in several more benefits to the Air Force:

- More effective system performance
- Significant improvement in user satisfaction
- Increased experience in operating a computer system in a medical environment
- Increased familiarity of medical staff with computers
- Continuity in a development effort that could lead to an integrated medical information system.

In order to obtain the maximum benefit from retaining AFCLAS at the two test sites, several steps must be taken:

- Make hardware and software modifications suggested by the laboratory staff and hospital staff, as appropriate.
- Provide software support using either in-house or contractor personnel.
- Designate the two installations as developmental rather than operational sites, thereby allowing for development and testing of improved methods of operation and management of a clinical laboratory in an automated data processing (ADP) environment.

The last item implies that there will be continual change in laboratory operations at a significantly greater rate than that expected in other laboratories. Rather than simply implementing an acceptable mode of operation, laboratory management would test new methods and would distinguish and document those that improve operations and those that do not. Serving as an experimental site would probably require additional staff. If this alternative is selected, the two test sites would become a resource for other military clinical laboratories and for the management of other hospital departments when they receive ADP equipment.

A third alternative would be to develop and install a scaled-down, stand-alone clinical laboratory computer system. This option was not studied; hence, the cost and benefits are not known.

H. Additional Observations

From the questionnaires and interviews with physicians, we realized that physicians expect certain things from clinical laboratories over which laboratory personnel have little control. For example:

- Rapid filing of reports
- Few errors in test requests
- Ability to telephone the laboratory without receiving a busy signal.

When laboratory personnel deliver reports to the wards or to Outpatient Medical Records, they have completed their processing of test requests. If reports are not filed promptly, it is a management problem involving ward and medical record personnel, not laboratory staff. Errors in request slips are generated outside the laboratory and, to

some extent, lead to distribution of reports to the wrong area. Physicians often complain about getting a busy signal when calling the clinical laboratory, but an analysis of telephone usage rates shows that installing a rotary capability on the phone system would reduce this irritant. Physicians may have hoped that AFCLAS would resolve these problems, but it could not because they are external to the clinical laboratory.

I. Conclusion

The evaluation of AFCLAS at the Wright-Patterson USAF Medical Center investigated both the dollar and nondollar benefits and costs of AFCLAS. A cost-benefit analysis showed that the expected dollar benefits and costs of operating AFCLAS (as configured in April 1976) yield a cost of $382,123 per year more than that of the previous manual system. In addition, there was a one-time cost of $91,123. The nondollar benefits are as follows:

- Probable improvement in patient care
- Provision of cumulative reports
- Improved legibility of reports
- Easy retrieval of test results
- Additional information on reports
- Improved report format.

A final conclusion on the overall cost-benefits of AFCLAS requires a judgment on the value of the nondollar benefits in relation to the net dollar benefits and costs.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This summary presents the most significant findings of an evaluation of the impacts of installing a medical information system, the Air Force Clinical Laboratory Automation System (AFCLAS), at the USAF Medical Center, Wright-Patterson AFB.

The evaluation plan was developed by identifying 58 potential impacts of introducing AFCLAS in place of the existing manual

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information system. Some of the areas investigated in the evaluation were clerical tasks inside and outside the clinical laboratory; completeness of the medical records; time for processing laboratory test requests; and acceptance by, or satisfaction of, various personnel and patient groups. Data were collected at two different times—before and after AFCLAS was installed.

The evaluation included a cost-benefit analysis, as well as an analysis of the nondollar benefits of AFCLAS. The cost-benefit analysis showed that the expected cost of operating a clinical laboratory using AFCLAS was $382,123 more per year than the cost of operating a clinical laboratory using the previous manual system. The one-time installation cost of AFCLAS was an additional $91,631. The nondollar benefits of AFCLAS are: probable improvement in patient care, provision of cumulative reports, improved legibility of reports, easy retrieval of test results, additional information on reports, and improved report format.